even though the air has been "cleaned." The structural design of stacks should be qualified by analysis in accordance with AA-4000. Care should also be exercised in the structural design so that stacks do not "crimp" or bend and cut off the effluent flow if they are subject to a strike by high wind- or tornado-generated missiles.

Openings in nuclear-safety-related structures for either air intakes or exhaust stacks should be protected from the effects of high wind or tornado missiles if such a missile could damage a nuclear-safety-related component and prevent it from functioning. Missile protection typically involves utilizing staggered building wall structures or a lattice of steel bars to prevent a straight-through missile path. Sufficient space must be allocated for these intake structures. Free-area reduction caused by the use of the staggered walls or steel bars in the openings must be considered when sizing the openings, particularly intakes, so that velocity requirements are not exceeded.

5.6 INSTRUMENTATION AND CONTROL

5.6.1 CODES AND STANDARDS REQUIREMENTS

Instrumentation and control systems, components, and equipment should meet the requirements of ASME AG-1, Section IA.[63] In addition, they should be qualified according to the requirements of IEEE 336,[79] 383,[80] and 384. [81]

5.6.2 FUNCTIONAL REQUIREMENTS

The function of the instrumentation and control systems associated with nuclear ventilation and nuclear air cleaning systems is to control the environment of the space served within the limits of the controlled variable, and to monitor the performance of the system and its components to ensure safe, efficient, reliable operation.

The design of instrumentation and control systems should consider the consequences of single failure[66] as well as environmental conditions.

The primary variables by which nuclear air cleaning systems are controlled are temperature, airflow rate, and pressure. Temperature, pressure, flow, and radioactivity levels are monitored to indicate system performance and alarm abnormal conditions.

Effluent air cleaning systems typically are controlled to maintain a minimum negative pressure or building pressure around a preselected flow rate. Habitability systems are usually controlled to maintain a constant airflow rate that is selected to maintain a positive pressure in the space served. Temperature is also usually controlled for habitability systems.

Instrumentation should be provided to monitor the radioactivity levels of effluent discharged into the atmosphere. Each discharge point that could potentially have concentrations exceeding Plant Technical Specification limits should be monitored. Airflow rates and concentrations of radioiodine, particulates, and noble gases are also required. Values in excess of established high limits should be alarmed in the control room. In addition, airflow rates and radioactivity levels for habitability systems should be monitored and alarmed.

The best indicator of system performance for continually operating systems is the radioactivity levels. Monitoring flow rates and concentrations both before and after air cleaning units could indicate trends in filter degradation. The controls recommended in ASME AG-1, Section IA, Appendix IA-C,[63] (should be provided to assist the operators in monitoring system performance).

5.6.3 AIRFLOW CONTROL

Airflow control is one of the most important control variables for nuclear air cleaning systems. Nuclear air cleaning system pressure could vary by as much as 25 to 30 percent, depending on system components, clean filter pressure drop, and the change-out pressure drop as shown in **TABLE 5.5.** It is recommended (and required by USNRC Regulatory Guides 1.52[7] and 1.140[8]) that airflow rates be maintained within $\pm$10 percent of design to prevent reduction in filter efficiency. The airflow rate is usually required to be automatically controlled by either (1) discharge or inlet control dampers, (2) variable inlet vanes, or (3) variable speed control.

to control the airflow rate, the flow first must be accurately measured. Flow should be measured where the air velocity profile is uniform. AMCA 201[25] and 203,[26] as well as *Industrial Ventilation*[36] provide guidance on the proper location of airflow sensing devices. Several manufacturers produce airflow measuring devices that can provide accurate averaged velocity pressures, as well as the instrumentation to convert velocity pressures to airflow rates.

An alternative method of controlling the airflow rate within $\pm$10 percent of design is to select a fan that has a steep performance curve such that a 25 percent change in pressure will not result in more than a 10 percent change in flow rate. This is difficult to achieve, however, due to system margins, system effect factors, and the ability to accurately calculate system pressures.

The choice of control dampers or inlet vanes will depend on fan type, required pressure reduction, and airflow uniformity. Control dampers must be sized to provide controllability. This requires higher velocities than the duct velocity to ensure the damper does not close down to less than 90 percent of full open to achieve the pressure reduction. This situation will usually result in "hunting" due to the inability to achieve flow stability.

If the pressure reduction required is 40 percent or more of the fan static pressure at the operating point, inlet vane control may be desirable.

An inlet vane control damper costs about three times more than equivalent parallel-blade or opposed blade dampers but, at a capacity reduction of 50 percent or less, it produces power savings that may average 25 percent compared to parallel-blade or opposed blade control dampers. Another factor that favors the inlet vane damper over a control damper in the duct is that it permits operation of the fan for long periods at much below the maximum efficiency of the fan. Full-open inlet vane dampers cause the fan to operate at some penalty to airflow, static pressure, and horsepower.

AMCA 201[25] recommends the use of variable vane inlet dampers when the fan is to be operated for long periods at reduced flow. The effectiveness of this damper stems from the fact that the inlet vanes generate a forced inlet vortex that rotates in the same direction as the fan impeller; similarly, any restriction of the fan inlet reduces the fan performance. Inlet vane dampers are of two types: integral (built-in) and add-on. The resistance and system effect of inlet vane dampers in the wide-open position must be considered in the original fan selection and system functional design. System effects of inlet vane dampers should be available from the fan manufacturer; if not, the system effect curves of AMCA 201[25] should be applied to account for pressure losses due to the use of these dampers.

Although variable vane inlet dampers generally provide smooth airflow control down to less than 30 percent of operating-point flow, there have been instances of severe vibration on large fans when the vanes were positioned between 30 and 60 percent opening. Because vibration is aggravated by system turbulence, consideration must be given to ways of ensuring smooth airflow patterns in the duct entering the damper and leaving the fan when inlet vane dampers are employed in high-velocity systems. Variable-pitch Vaneaxial fans may also be used to maintain system flow under varying pressure conditions. Variable pitch fans, however, may not be qualifiable for safety-related, seismic applications that require environmentally qualified components.

With the increase in variable air volume air conditioning systems, much has been done to improve variable speed controls for fans. Variable frequency controls, eddy current clutch motors, and mechanical adjustable speed drives are various methods of speed controls for fans. For variable air volume air conditioning systems, the airflow rate is varied to maintain a constant system pressure. For nuclear air cleaning systems, the speed of the fan is varied to maintain a constant airflow under varying system pressures.

Adjustable frequency drives are becoming more economical due to lower-cost solid state electronic components. The speed of the fan motor is directly proportionate to the frequency of the motor. Since the horsepower of the fan is a function of the cube of the speed, there can be significant secondary benefits of saving energy by using frequency drives, as well as better matching of fan performance to changing system pressure requirements.

One disadvantage of these types of speed control is a potential lack of environmental qualification data in accordance with IEEE 323,[73] and quality assurance programs in accordance with 10 CFR 50, Appendix B,[51] which are required for safety-related equipment. However, for non-nuclear-safety-related applications, these requirements do not apply and speed control is a possible option to consider.

5.6.3 PRESSURE CONTROL

Effluent air cleaning systems are typically controlled to vary the system flow rate to maintain building (or space) pressure. This is accomplished by maintaining constant supply airflow and varying exhaust flow by adjusting control dampers and inlet vanes, and through speed control similar to the techniques described in Section 5.6.2. Accurately sensing building pressure and outside air pressure is important for achieving a stable operating system. The sensing system should incorporate a "dead leg" to dampen the system reaction to wind gusts. Multiple outdoor and, if necessary, indoor sensors should be provided to obtain an average outside air pressure. To maintain a building at a negative pressure with respect to the lowest outside air pressure, the outdoor sensors should be located on each exposure. The system should then be designed to control flow based on the highest positive pressure sensed (the one that would result in the most infiltration

Sensors should be located with due consideration given to local pressure fluctuations, eddy currents, and the turbulence that can be experienced at building corners and roof edges. Chapter 14 of the *ASHRAE Handbook of Fundamentals* provides guidance on determining turbulent zones due to airflow around buildings. This information must be considered in locating the sensors.

5.6.4 QUALIFICATION AND TESTING

All instruments used in ESF nuclear safety air cleaning systems must be qualified for environmental and seismic conditions in accordance with ASME AG-1, Section IA,[63] IEEE 323,[73] and IEEE 344.[76]

All instruments and devices must be calibrated and tested in accordance with manufacturer's test procedures. In addition, all power wiring internal to control panels, except control or shielded cable, should be subjected to a high-potential test to demonstrate freedom from ground and correct wiring connections.

It is recommended that extensive onsite pre-operational testing be performed on all instrumentation and control systems associated with nuclear air cleaning systems prior to placing the systems in service. Pre-operational testing should be performed to confirm correct installation and design and to ensure correct operability of the control system and operated equipment. USNRC Regulatory Guides 1.68[77] and 1.68.3[78] provide guidance on what should be considered in pre-operational tests.

5.7 Other Considerations

5.7.1 Security

Ductwork, openings for intakes and exhaust stacks, and other types of building penetrations and pathways must be properly protected against security threats. Security measures for these openings and pathways are addressed in the facility security requirements.

5.7.2 ENERGY CONSERVATION

Specialized products and components for energy conservation may be appropriately used for the facility HVAC systems. In employing these components, care must be exercised to avoid using products that cannot be decontaminated or would otherwise limit the ability of the air cleaning systems to perform their design basis functions.

5.8 REFERENCES

1. *ASHRAE (*American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.,), *2000 Systems and Equipment Handbook s,* Chap. 2, “Building Air Distribution,” and Chap. 16, “Duct Construction,” Atlanta, GA,. 2000.